SEE Evaluation of Digital Analog Converters for Space Applications

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Abstract

SEE cross-sections were obtained for four different Digital to Analog Converters (DACs). The different types of DAC tested were: the Analog Devices DAC8420, the Analog Devices AD768, the Maxim MAX539, and the Xicor X9C503. Both of the Analog Devices DACs and the Maxim part were seen to be immune to latch-up, not latching even at 120 MeV-cm^2/mg. The Xicor part did latch-up with a threshold of 25 MeV-cm^2/mg. Both Analog Devices DACs had clocked inputs which when constantly clocked rendered the device immune to SEU on the output line. The Xicor DAC had no clock option or function. All four devices had thresholds around 5 MeV-cm^2/mg for output SEU.

I. Introduction

Due to the ever increasing need for viable space avionics systems, more and more Commercial-Off-the-Shelf (COTS) parts are being investigated for application in radiation environments. The science and control requirements for deep space and near earth missions are becoming more and more intricate and demanding. Analog and digital/analog devices, which are vulnerable to radiation, are becoming critical parts in many systems. Some devices have already been tested [1]. This paper reports on three devices that have been flown in NASA space missions.

II. DAC Devices

Several of each device type were tested for response under heavy ions. The devices were encased in plastic, which were easily delidded for exposure to heavy ions.

Table 1. Properties of the DAC devices under test.

Device	Man.	Width	Tech.
AD768	Analog Devices	16 Bit	ABCMOS
AD8420	Analog Devices	12 Bit	CMOS
MAX539	Maxim	12 Bit	CMOS
X9C503	Xicor	8 Bit	CMOS

II. Test Setup And Procedure

The test equipment was comprised of two PCs, a power supply, and a specially designed test board. One PC controlled a HP6629A power supply. This allowed precision voltage control and latch-up detection and protection since the PC had millisecond control over the operation of the power supply. Latch-ups were recorded in a separate file during the test.

A dedicated PC controlled the test circuit board designed specifically for this DAC test to read and write to the DUTs. Custom daughter boards allow each DAC type to be tested by the same test board. This setup allows complete freedom to interact with the DUT. This allowed for any structure in the SEEs or predilection for certain pattern failure or type of SEU to be observed. A depiction of the setup used is shown in Figure 1. Testing was done at the Texas A&M cyclotron.

Table 2. Ions used in testing.

Particle	Energy(MeV)	InitialLET(Si) (MeV cm2/mg)	Range µm	LETmax (MeV cm2/mg)	Range(LET max) µm
Ne	546	1.74	799	9.65	790
Ar	1000	5.41	500	20.1	491
Kr	2100	19.2	336	41.4	315
Xe	3200	37.9	286	63.4	254

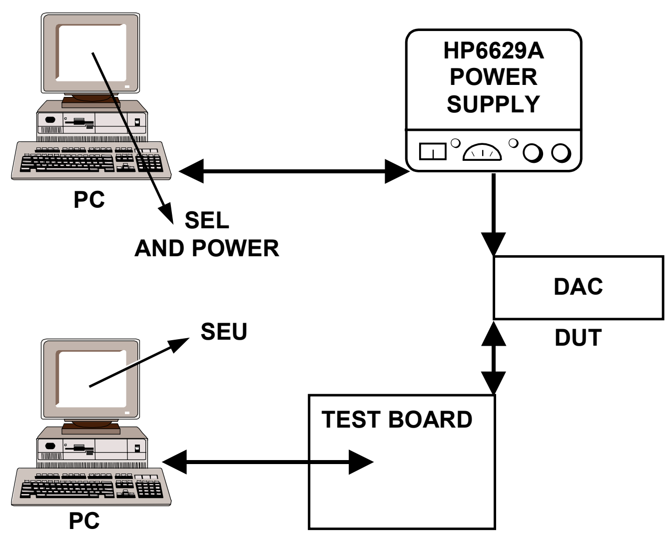

Figure 1. A block diagram of the test system.

To measure the effects of heavy ions on the device, the voltage outputs of two differential outputs are compared, one under test and one as a reference. The dual DACs structure allows for easy tuning for the threshold of which a voltage interrupt, the primary SEE, can be seen. Resolution down to the LSB could be tested in this manner. The DUT was always tested at minimum or maximum output, while the reference device is tuned to give the test board maximum sensitivity. The board used an ultra-high gain amplifier circuit to measure small output SEE effects.

The Vdd voltage was always set to 5 volts and the operating temperature was approximately 25 °C throughout the study.

IV. Heavy Ion Results

A. SEU Results

Most of the devices had similar results. All of the devices were programmed and read using the same handshaking protocol. To measure any catastrophic effects, one of each of the devices was exposed to more than 10^7 cm^{-2} ions with no latch-up protection. All of these DUTs were seen to work after the exposure. No stuck bits or residual programming problems were seen in any of the devices. Error bars on all graphs are based on Poisson counting statistics. Some exposures were done during programming or reading to determine any contribution these processes. No dependence was seen.

Analog Devices DAC8420

Voltage Interrupt SEU

The results of the test of all of the devices are shown in Figure 2. Three devices were tested and there was negligible variation between them. The curve shown in Figure 2a has up to an order of magnitude variation in cross section due to inherent flicker noise in the system. Figure 2b shows the data divided among the six devices that were tested. Figure 2c shows the results of averaging the data at each redundant LET. All figures are fit a model given by Edmonds [2]. All of these SEU occur in the standby mode. A simple reclocking of the data reset the device.

Analog Devices DAC768

Voltage Interrupt SEU

The results of the test of all of the devices are shown in Figure 3. Three devices were tested and there was negligible variation between them. The curves shown in Figure 3 also have up to an order of magnitude variation in cross-section, mainly from noise. Figure 3b shows the data divided among the three devices that were tested. Figure 3c shows the results of averaging the data at each redundant LET. The error bars are the standard deviations of the redundant measurements. All figures are fit a model given by Edmonds [2]. All of these SEU occur in the standby mode. A simple reclocking of the data reset the device.

The device was tested at constant oscillation frequencies of 0.5, 1, and 12 MHz. No SEUs were seen at these frequencies. The device is apparently immune to SEU effects at frequencies over 0.5 MHz.

Xicor X9C503

Voltage Interrupt SEU

The results of the test of all of the devices are shown in Figure 4. Three devices were tested and there was negligible variation between them. Figure 4b shows the response of the device in the high and low output mode. The error bars are the standard deviations of the redundant measurements. Figure 4c shows the data divided among the three devices that were tested. Figures are fit to a model given by Weibull. All of these SEU occur in the standby mode. A simple reclocking of the data reset the device.

Maxim MAX539

Voltage Interrupt SEU

The results of the test of all of the devices are shown in Figure 6. two devices were tested and there was negligible variation between them. Figure 6a shows the response of the device in the high and low output mode. The error bars are the standard deviations of the redundant measurements. Figure 6b shows the data divided among the three devices that were tested. Figures are fit to a model given by Edmonds. All of these SEU occur in the standby mode. A simple reclocking of the data reset the device.

B. SEU Thresholds

The LET threshold of the device was found using two definitions. The typical 10% of saturation value definition was used. Another definition was the LET at which the cross-section would be the inverse of the number of bits multiplied by the estimated die area.

C. SEL Results

The AD768, the MAX539, and the DAC8420 experienced no SEL. The Xicor experienced Single Event Latch-ups at a LET of 22 MeV-cm^2/mg. Figure 5 shows the latch-up of this device. LETs up to 120 MeV-cm^2/mg were tested. Extreme angles and lower energy ions, which should have experienced end of range phenomenon in the sensitive volume of the latch-up no angular sensitivity was seen.

V. Conclusion

The radiation testing of these DACs has shown that CMOS DAC technology is very sensitive to SEU and less sensitive to SEL. The devices can be used in radiation environments as along as counter measures are used.

Table 3. Thresholds for various DACs.

Device	Clocking Over 500 kHz	SEL Threshold (MeV cm^2/mg)	SEU Threshold (MeV cm^2/mg)	SEU Saturation Device Cross-section[cm2]
X9C503	N/A	25	5	1e-3
AD8420	Yes	>120	>120	N/A
AD8420	No	>120	7.5	1.5e-4
MAX539	N/A	>120	5	1e-4
AD768	Yes	>120	N/A	N/A
AD768	No	>120	7.5	1.91e-4

Acknowledgments

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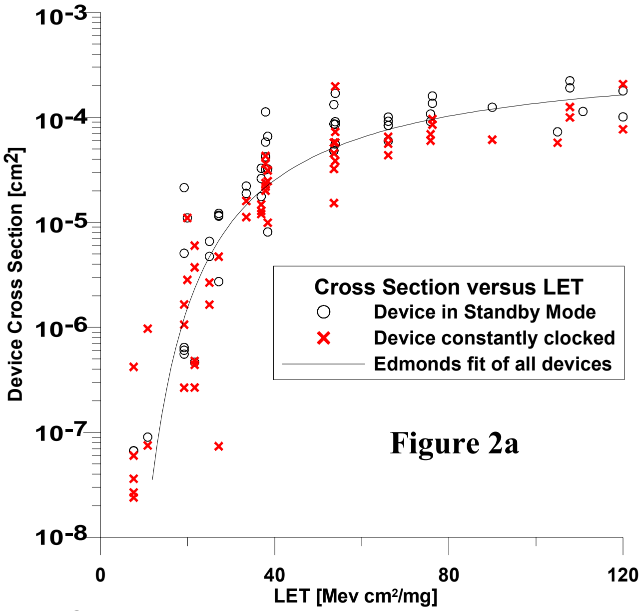
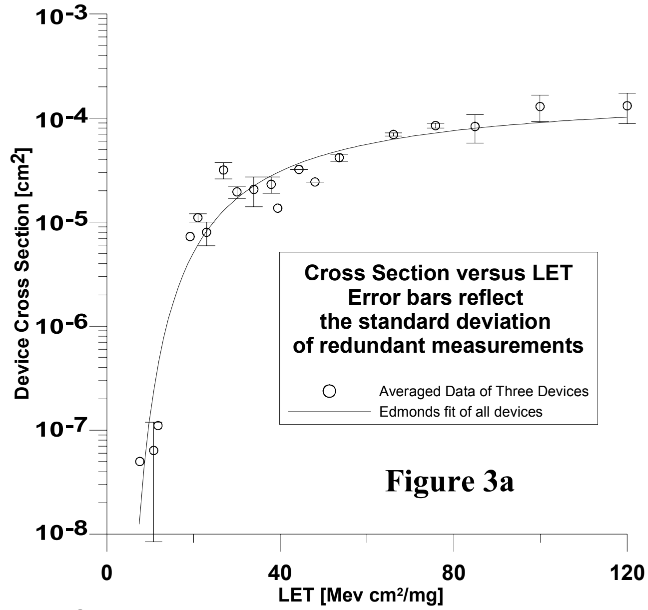
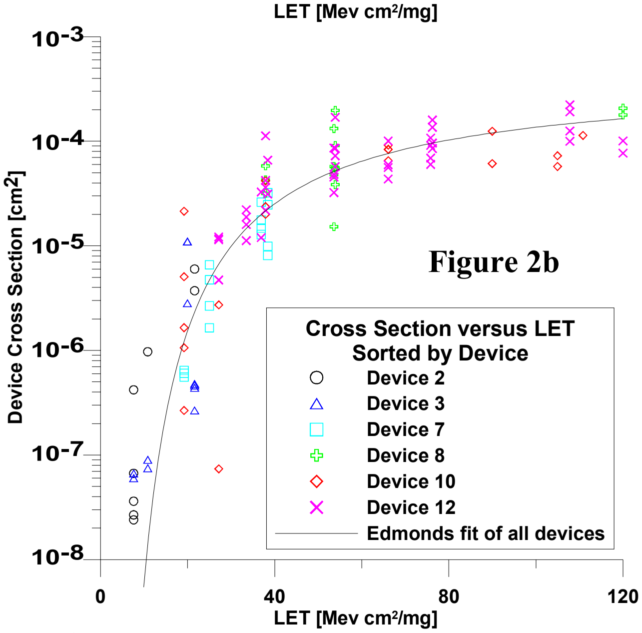
References

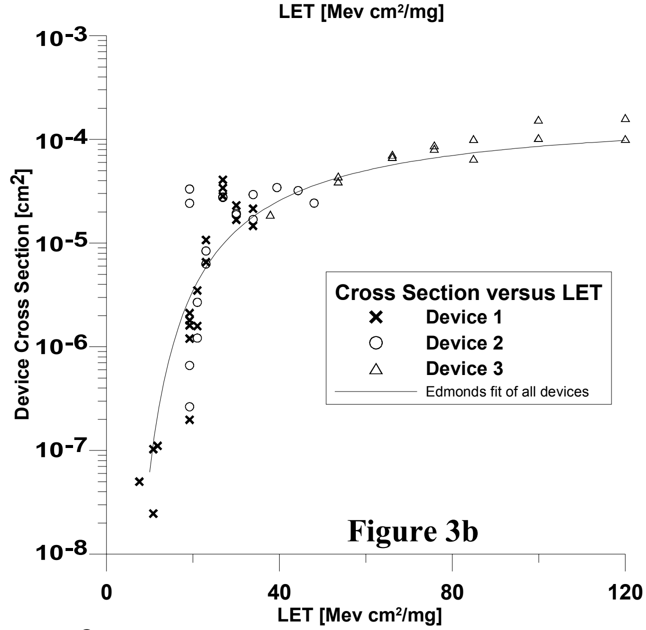
[1] O'Bryan, M.V.; LaBel, K.A.; Reed, R.A.; Barth, J.L.; Seidleck, C.M.; Marshall, P.; Marshall, C.; Carts, M. *Single event effect and radiation damage results for candidate spacecraft electronics*, Radiation Effects Data Workshop, 1998. IEEE , 1998 Page(s): 39 -50

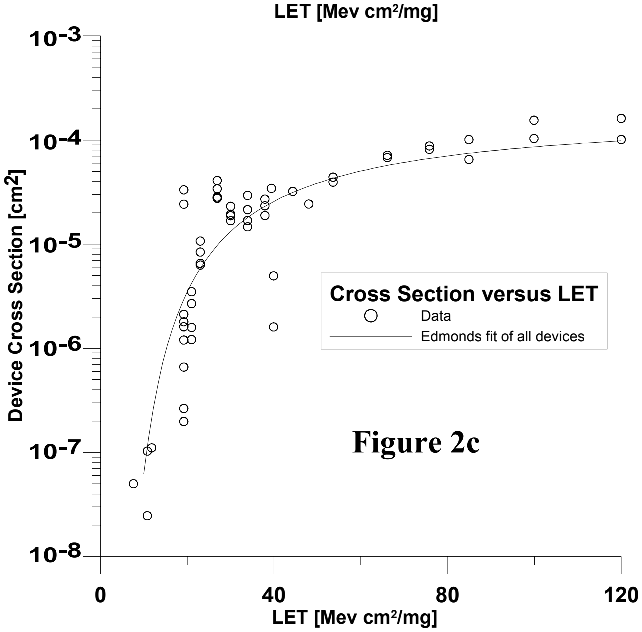
[2] Edmonds, L.D., *SEU Cross Sections Derived From A Diffusion Analysis*, , IEEE Transactions on Nuclear Science, Volume: 43 Issue: 6 Part: 2 , Dec. 1996 Page(s): 3207 -3217

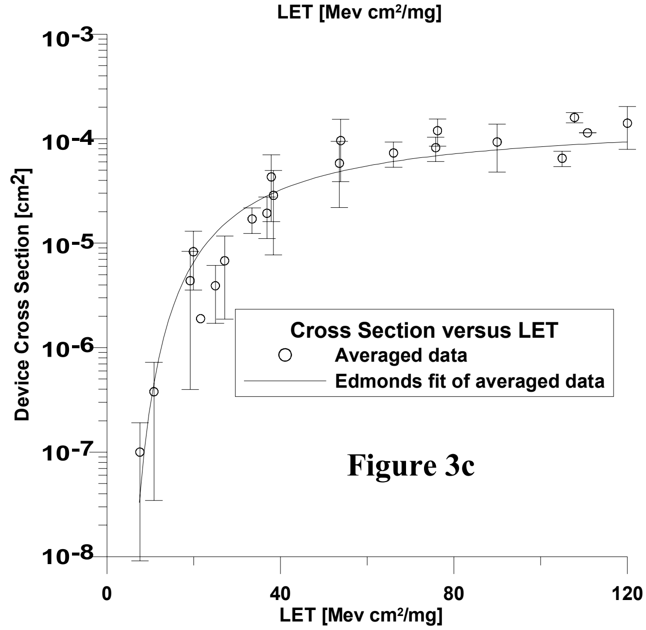

Device Cross Section [cm2]
LET [Mev cm²/mg]
Cross Section versus LET
Device in Standby Mode
Device constantly clocked
Edmonds fit of all devices
Figure 2a


Device Cross Section [cm2]
LET [Mev cm²/mg]
Cross Section versus LET
Error bars reflect
the standard deviation
of redundant measurements
Averaged Data of Three Devices
Edmonds fit of all devices
Figure 3a


Device Cross Section [cm2]
LET [Mev cm²/mg]
Cross Section versus LET
Sorted by Device
Device 2
Device 3
Device 7
Device 8
Device 10
Device 12
Edmonds fit of all devices
Figure 2b


Device Cross Section [cm2]
LET [Mev cm²/mg]
Cross Section versus LET
Device 1
Device 2
Device 3
Edmonds fit of all devices
Figure 3b


Device Cross Section [cm2]
LET [Mev cm²/mg]
Cross Section versus LET
Data
Edmonds fit of all devices
Figure 2c


Device Cross Section [cm2]
LET [Mev cm²/mg]
Cross Section versus LET
Averaged data
Edmonds fit of averaged data
Figure 3c

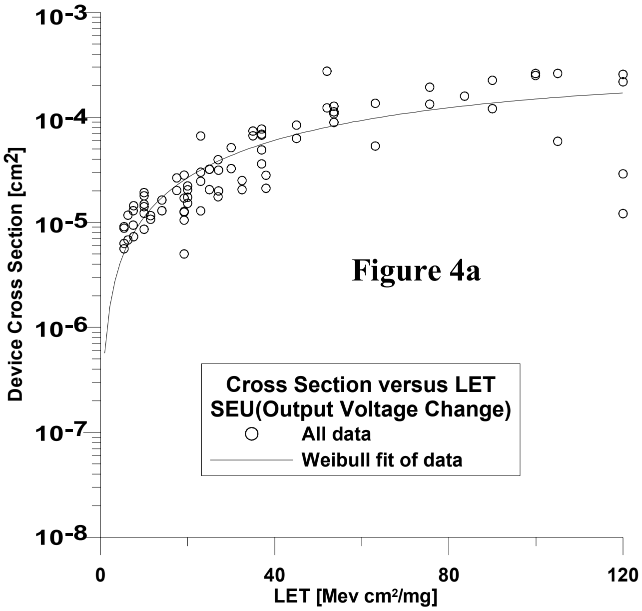


Figure 4a
Cross Section versus LET
SEU(Output Voltage Change)
All data
Weibull fit of data
Device Cross Section [cm2]
LET [Mev cm2/mg]
10-3
10-4
10-5
10-6
10-7
10-8
0
40
80
120

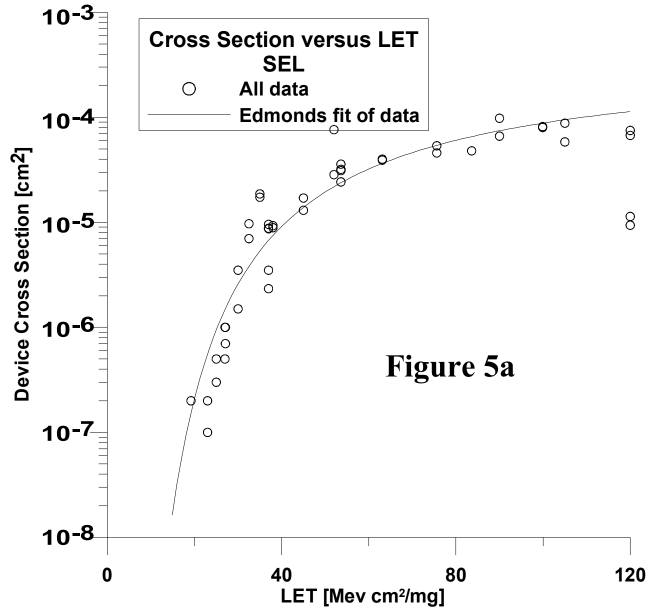


Figure 5a
Cross Section versus LET
SEL
All data
Edmonds fit of data
Device Cross Section [cm2]
LET [Mev cm2/mg]
10-3
10-4
10-5
10-6
10-7
10-8
0
40
80
120

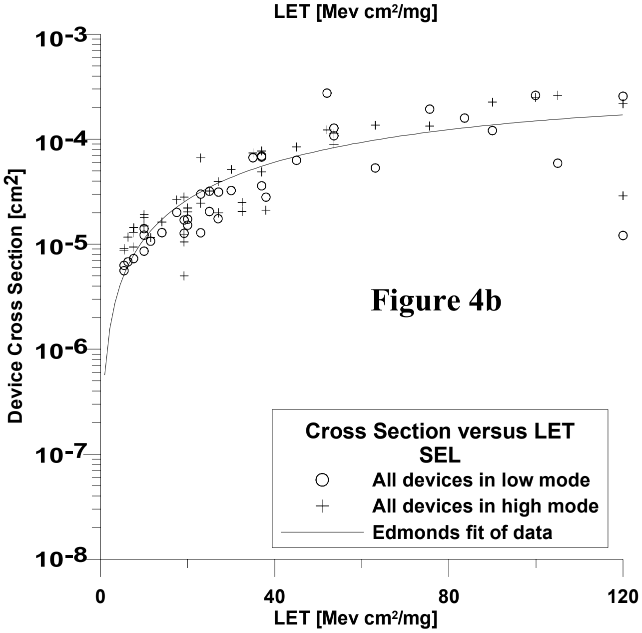


Figure 4b
Cross Section versus LET
SEL
All devices in low mode
All devices in high mode
Edmonds fit of data
Device Cross Section [cm2]
LET [Mev cm2/mg]
10-3
10-4
10-5
10-6
10-7
10-8
0
40
80
120

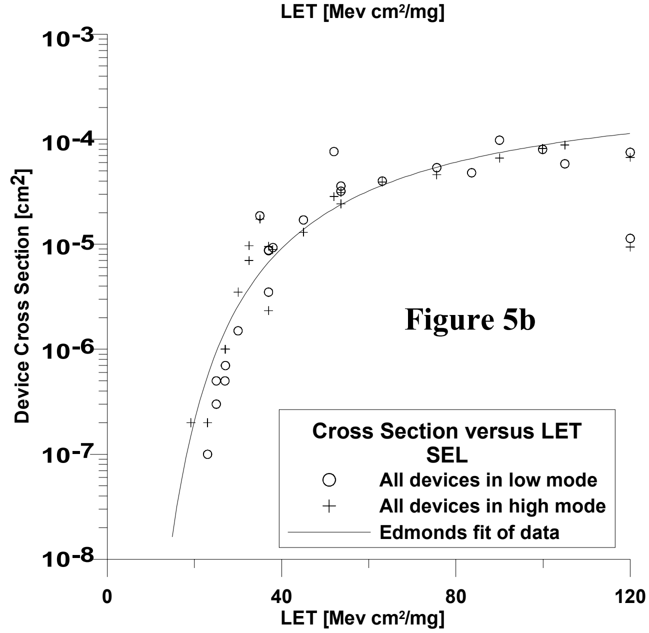


Figure 5b
Cross Section versus LET
SEL
All devices in low mode
All devices in high mode
Edmonds fit of data
Device Cross Section [cm2]
LET [Mev cm2/mg]
10-3
10-4
10-5
10-6
10-7
10-8
0
40
80
120

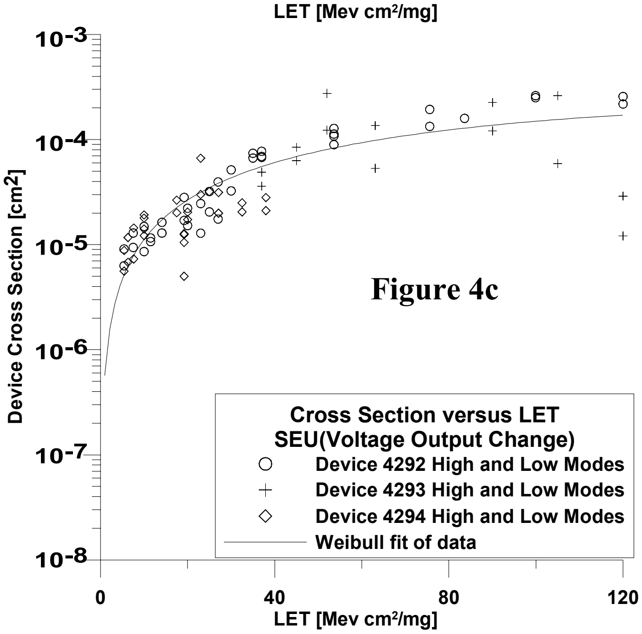


Figure 4c
Cross Section versus LET
SEU(Voltage Output Change)
Device 4292 High and Low Modes
Device 4293 High and Low Modes
Device 4294 High and Low Modes
Weibull fit of data
Device Cross Section [cm2]
LET [Mev cm2/mg]
10-3
10-4
10-5
10-6
10-7
10-8
0
40
80
120

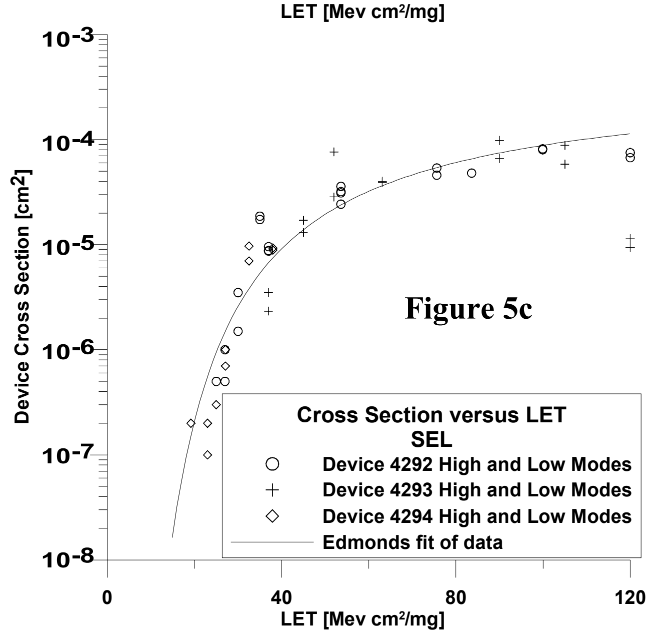


Figure 5c
Cross Section versus LET
SEL
Device 4292 High and Low Modes
Device 4293 High and Low Modes
Device 4294 High and Low Modes
Edmonds fit of data
Device Cross Section [cm2]
LET [Mev cm2/mg]
10-3
10-4
10-5
10-6
10-7
10-8
0
40
80
120

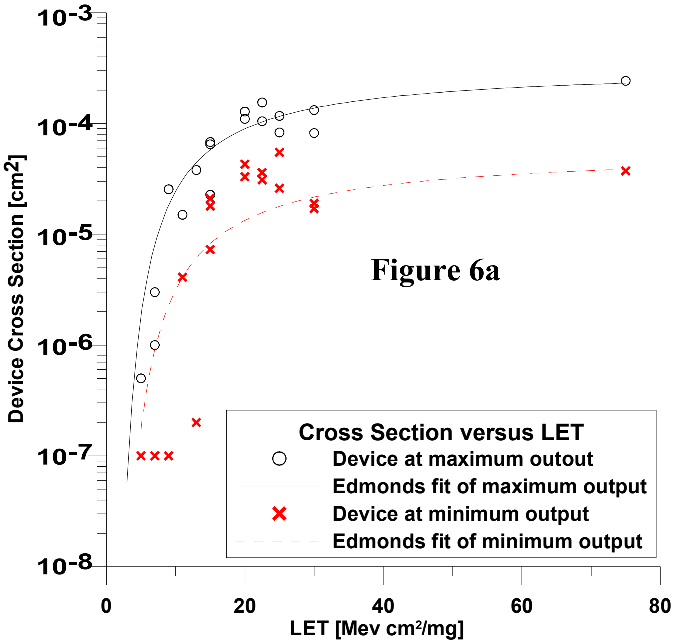


Figure 6a
Device Cross Section [cm2]
10-3
10-4
10-5
10-6
10-7
10-8
0
20
40
60
80
LET [Mev cm2/mg]
Cross Section versus LET
Device at maximum outout
Edmonds fit of maximum output
Device at minimum output
Edmonds fit of minimum output

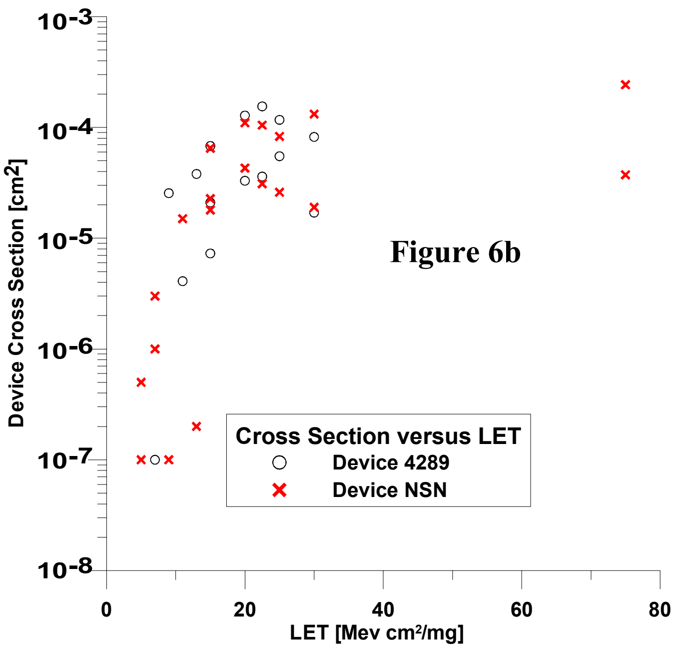


Figure 6b
Device Cross Section [cm2]
10-3
10-4
10-5
10-6
10-7
10-8
0
20
40
60
80
LET [Mev cm2/mg]
Cross Section versus LET
Device 4289
Device NSN